Anomalous Lunar Reconnaissance Orbiter (LRO) range rate measurements

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Two different sets of Lunar Reconnaissance Orbiter (LRO) range rate measurements, both extracted from the same publicly-available LRO data, yield different results on the order of 0.001% of either measurement. Though very small and insignificant in terms of navigational need, this measurement difference is nonetheless definite, and exhibits a pattern which varies from Moon-center to Moon-limb with respect to where LRO transmitted its radio navigation signal. The angle rate difference pattern can be approximated as a simple cosinusoidal function.

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BACKGROUND

During post-nominal science operations in 2012 and 2013, the NASA Lunar Reconnaissance Orbiter (LRO) spacecraft was in an elliptical polar orbit with a perigee of 40 km and an apogee of 180 km, with an orbit period of ∼118 minutes. In addition to conducting a variety of scientific experiments and a laser-ranging experiment, LRO communicated ordinary engineering telemetry via S-band radio transceiver.

Various characteristics of the S-band carrier signal can be extracted from publicly-available navigation data [1] using NASA GSFC document 450-TAH-STDN [2]. These extractable characteristics include Doppler range rate and round-trip light time (RTLT). Given RTLT, the exact range R_n of the spacecraft range rate at any given time can be calculated via $R_n = c \cdot \mathrm{RTLT}_n$.[1] Thus a secondary range rate calculation can be made using $(R_{n+1} - R_n)/(T_{n+1} - T_n)$, and can be compared to the primary range rate calculation via Doppler at equivalent timestamps.

RANGE RATE MEASUREMENT COMPARISON METHOD

Data can be organized into sets of similar LRO orbits by organizing the data into groups where the data in each group has roughly the same beta-angle[2] between spacecraft orbit and earth observer.

Range rates, derived from Doppler and alternately from $(R_{n+1}-R_n)/(T_{n+1}-T_n)$, can be averaged to remove random imprecision inherent in either or both range rate measurements. By performing such averaging for measurements at LRO orbit positions, which are comparable in terms of LRO orbit phase (i.e., some time offset within the LRO orbital period), random imprecision can be mitigated for each orbit phase offset. Such measurements per orbit beta-angle and orbit phase offset will be called an LRO “orbit phase bin.”

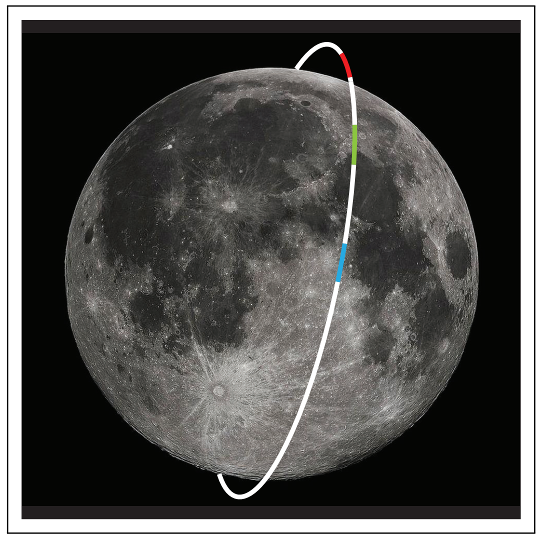

FIG. 1: Consider two LRO orbits having identical beta angles: distinct orbit phase bins are illustrated in red, green, and blue (red closest to the limb). Data from each respective phase bin from one orbit can be averaged with data from the other orbit in the same bin.

DATA ANALYSIS RESULTS

For an example data range in years 2012 and 2013, the average data difference shows a small but noticeable cosinusoidal difference pattern, though not the same as what was found by other analysis [3].

This result may be similar to the observed solar center-to-limb variation of the solar wavelength [4–6]. It is also possible that this cosinusoidal difference pattern conforms to a correlated anomaly predicted by A. F. Mayer, prior to LRO launch [7].

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[1] $c \equiv$ speed of light

[2] The referenced “beta-angle” is the angle between the spacecraft’s lunar orbit plane and the Moon-Earth line.

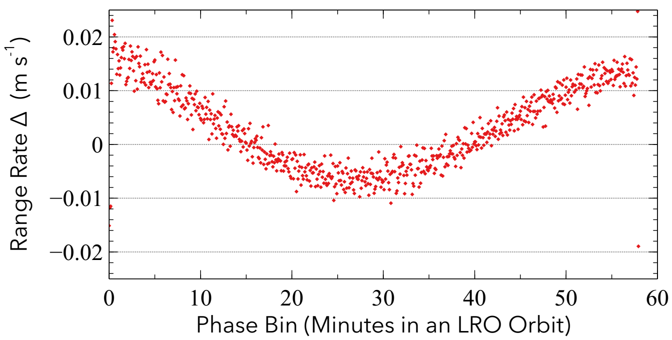

FIG. 2: Average Difference Between Range Rate Measurements per Phase Bin.

As a sidenote, the pattern could be a result of some other anomaly, or the pattern could simply be the result of incorrect interpretation of data timestamps while reducing the data (by the author, M. A. Yang). In addition, other data in other formats was also collected for this S-band transceiver, but was not in a raw format as found in that which could be extracted using the information in the 450-TAH-STDN document. The data in the other format (unrelated to this paper) was reported by NASA to have no anomalies present [3].

CONCLUSION

Two sets of range-rate measurements, derived from the same publicly-available dataset, yield slightly different results; that difference conforms to a cosinusoidal pattern and constitutes an anomaly that requires explanation.

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[1] → NASA Planetary Data System (PDS)
→ Geosciences Node
→ Lunar Reconnaissance Orbiter (LRO)
→ Radio Science (RS) Archive
→ Tracking data from ground stations, subdivided by mission subphase and then by day (DATA/TRK)

[2] Goddard Space Flight Center/Code 531, "Tracking and Acquisition Handbook for the Spaceflight Tracking and Data Network," 450-TAH-STDN, 1994.

[3] S. Slojkowski (private communications, 2011–2012).

[4] J. Evershed and T. Royds, Kod. Obs. Bull., **3**, 145 (1916).

[5] D. Samain, A&A **244**, 217 (1991).

[6] C. Gallo, "Our Sun's Center-to-Limb Redshift: A Puzzle," APS April Meeting, abstract id. D1.003 (2005).

[7] A. F. Mayer, "The Geometry of Time in General Relativity," APS April Meeting, abstract id. D11.009 (2009).